arXiv:nucl-th/0608065v1   28 Aug 2006

PION AND KAON PRODUCTION
IN NUCLEON - NUCLEON COLLISIONS.

MARTA TICHORUK

Institute of Physics, Jagiellonian University
PL-30-059 Cracow, Poland

ANTONI SZCZUREK

Institute of Nuclear Physics
PL-31-342 Cracow, Poland
and
University of Rzeszów
PL-35-959 Rzeszów, Poland
Antoni.Szczurek@ifj.edu.pl

Inclusive cross section for pion production in proton - proton collisions are calculated based on unintegrated parton distribution functions (uPDFs). In addition to purely gluonic terms the present approach includes also quark degrees of freedom. Phenomenological fragmentation functions from the literature are used. The new mechanisms are responsible for π^+ - π^- asymmetry. In contrast to standard collinear approach, application of $2 \rightarrow 1$ k_t - factorization approach can be extended towards much lower transverse momenta, both at mid and forward rapidity region. The results of the calculation are compared with SPS and RHIC data.

Keywords: unintegrated parton distributions; fragmentation functions; inclusive cross section.

PACS numbers: 11.25.Hf, 123.1K

1. Introduction

The distributions of mesons at large transverse momenta in pp or $p\bar{p}$ collisions are usually calculated in the framework of perturbative QCD using collinear factorization (see e.g.[1,2,3,4]). While the shape at transverse momenta larger than 2-4 GeV can be relatively well explained, there are discrepancies at lower transverse momenta. In this analysis, the calculations are performed using a new approach, based on the unintegrated parton distributions. In recent years only gluon degrees of freedom are taken explicitly in this context [9]. In the present analysis, in addition to the $gg \rightarrow g$ mechanism, We include also $q_f g \rightarrow q_f$ and $g q_f \rightarrow q_f$ mechanisms and similar ones for antiquarks, in order to obtain a fully consistent description.

The new contributions $q_f g \to q_f$ and $gq_f \to q_f$ are comparable to the contribution of the $gg \to g$ diagram at midrapidities and are dominant in the fragmentation region. The new mechanisms are responsibile for $\pi^+ - \pi^-$ asymmetry. A purely gluonic mechanism would lead to identical production of positively and negatively charged hadrons. The recent results of the BRAHMS experiment [11] show that the π^-/π^+ and K^-/K^+ ratios differ from unity. This put into question the successful description of Ref.[9]. In the light of this experiment, it becomes obvious that the large rapidity regions have more complicated flavour structure. At lower energies these ratios are known to differ from unity drastically [20]. Many unintegrated gluon distributions in the literature are ad hoc parametrizations of different sets of experimental data rather than derived from QCD. Recently Kwieciński and collaborators [13,14,15] have shown how to solve the so-called CCFM equations by introducing unintegrated parton distributions in the space conjugated to the transverse momenta [13]. We present results for pion and kaon production based on the unintegrated parton (gluon, quark, antiquark) distributions.

2. Inclusive cross section for partons

The formulae for inclusive quark/antiquark distributions are similar to the formula for $gg \to g$ [12]

$$\frac{d\sigma^A}{dy d^2 p_t} = \frac{16 N_c}{N_c^2 - 1} \frac{1}{p_t^2}$$
$$\int \alpha_s(\Omega^2) \, f_{g/1}(x_1, \kappa_{1_t}^2, \mu^2) \, f_{g/2}(x_2, \kappa_{2_t}^2, \mu^2)$$
$$\delta^{(2)}(\vec{\kappa}_{1_t} + \vec{\kappa}_{2_t} - \vec{p}_t) \, d^2 \kappa_{1_t} d^2 \kappa_{2_t} \,, \tag{1}$$

These seemingly 4-dimensional integrals can be written as 2-dimensional integrals after a suitable change of variables [10]. The formulae can be written in the equivalent way in terms of the parton distributions in the space conjugated to the transverse momentum [21].

3. Inclusive cross section for hadrons

There are a few sets of fragmentation functions available in the literature, details were described e.g. in [16], [17], [22]. The inclusive distributions of hadrons (pions, kaons, etc.) can be obtained through a convolution of inclusive distributions of partons and flavour-dependent fragmentation functions. One dimensional distributions of hadrons can be obtained through the integration over the other variable (see [21]).

4. Results

In Fig. 1 we compare the model invariant cross sections for $pp \to \pi^+$ (left panel) and $pp \to \pi^-$ (middle panel) as a function of pion transverse momentum at W =

27.4 GeV for different values of the parameter b_0 of our Gaussian nonperturbative form factor (for explanation see [21]) with the experimental data from Ref.[19], [20]. In principle, the result should not exceed experimental data especially in the perturbative regime of $p_t > 2$ GeV where the perturbative $2 \rightarrow 2$ parton subprocesses are crucial. This limits the value of the nonperturbative form factor to $b_0 > 0.5$ GeV^{-1}. Inclusion of diagrams B_1 (q_f g $\rightarrow$ q_f) and B_2 (g q_f $\rightarrow$ q_f) (see [21]) in conjunction
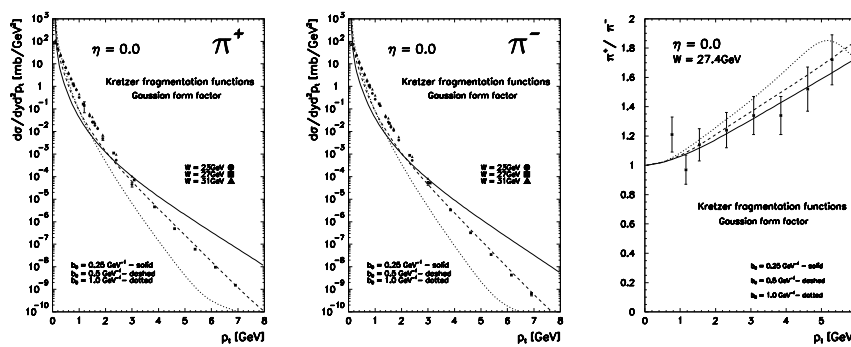

Fig. 1.   Invariant cross section as a function of transverse momentum of π^+ (left panel) and π^- (right panel) for $\eta = 0$, W = 27.4 GeV and different values of parameter b_0 of the Gaussian form factor. Experimental data for W = 23, 31 GeV from [19] and for W = 27.4 GeV [20] are shown for comparison.

with the flavour dependent fragmentation functions leads to the $\pi^+ - \pi^-$ asymmetry. In the right panel of Fig.1 we show the asymmetry as the function of pion transverse momentum. The asymmetry is well described by this model, in contrast to individual distributions. This seems to suggest the right relative contributions of diagram A (gg $\rightarrow$ g), B_1 and B_2. The asymmetry depends only weakly on the value of the parameter b_0 of the Gaussian nonperturbative form factor.

The PHENIX collaboration has measured invariant cross section as a function of the π^0 transverse momentum at W = 200 GeV in a very narrow interval of pseudorapidity $\eta = 0.0 \pm 0.15$. In Fig.2 we show full result (diagrams A, B_1 and B_2 [21],[24]) for different fragmentation functions [16,17,22].

In Fig.3 we present dependence of the invariant cross section for kaon production, calculated for W = 27.4 GeV, on the value of the parameter b_0 of the Gaussian nonperturbative form factor. The data for $p_t > 0.5$ GeV are well described by the k_t-factorisation approach with the Kwieciński UPDFs for the parameter $b_0 = 0.5$ GeV^{-1}. This is the same value of the paramater as that obtained for pions in the same energy range (see Fig. 1). More examples can be found in [24] and [25].

5. Conclusions

The formalism based on uPDFs, which fulfill so-called Kwieciński evolution equations, provides a reasonable description of the experimental data, including SPS as
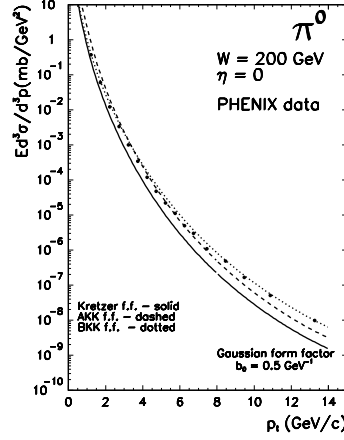
4   *Marta Tichoruk*

Fig. 2.   Invariant cross section for π^0 production as a function of pion transverse momentum at W = 200 GeV and $\eta = 0.0$. The k_t-factorization results are shown for different sets of fragmentation functions. The experimental data of the PHENIX collaboration are from [23].

well as recent data of the PHENIX, BRAHMS and STAR collaborations. A good agreement with experimental data is obtained, especially at relatively small transverse momenta and large values of pseudorapidity. The mechanisms, which invole quark/antiquark degrees of freedom are significant and lead to an asymmetry in the production of π^+ and π^- mesons.
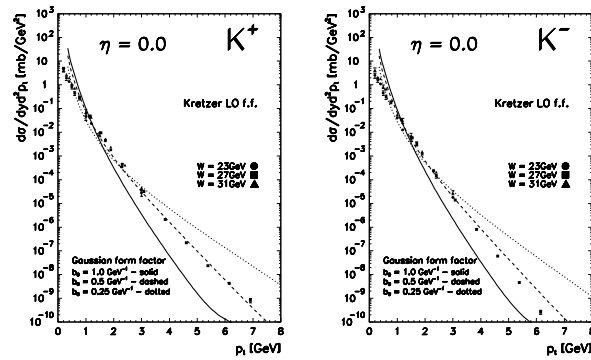
Acknowledgments

Fig. 3.   Dependence of the invariant cross section for kaon production on the value of the parameter b_0 of the Gaussian nonperturbative form factor.

References

1. J.F. Owens, Rev. Mod. Phys. **59** (1987) 465.
2. R. D. Field, Application of Perturbative QCD (Addison-Wesley, Reading, MA, 1995).
3. K.J. Eskola and K. Kajantie, Z. Phys. **C75** (1997) 515.
4. K.J. Eskola and H. Honkanen, Nucl. Phys. **A713** (2003) 167.
5. G.G. Barnafoldi, G. Fai, P. Levai, G. Papp, Y. Zhang, J. Phys. **G27** (2001) 1767.
6. X.-N. Wang, Phys. Rev. **C61** (2000) 064910.
7. Y. Zhang, G. Fai, G. Papp, G.G. Barnafoldi and P. Levai, Phys. Rev. **C65** (2002) 034903.
8. G. Papp, G.G. Barnafoldi, P. Levai and G. Fai, hep-ph/0212249.
9. D. Kharzeev and E. Levin, Phys. Lett. **B523** (2001) 79.
10. A. Szczurek, Acta Phys. Polon. **B34** (2003) 3191.
11. R. Karabowicz et al.(BRAHMS collaboration), Nucl. Phys. **A774** (2006) 477.
12. L.V. Gribov, E.M. Levin and M. G. Ryskin, Phys. Lett. **B100** (1981) 173.
13. J. Kwieciński, Acta Phys. Polon. **B33** (2002) 1809.
14. A. Gawron and J. Kwieciński, Acta Phys. Polon. **B34** (2003) 133.
15. A. Gawron, J. Kwieciński and W. Broniowski, Phys. Rev. **D68** (2003) 054001.
16. J. Binnewies, B.A. Kniehl, G. Kramer, Phys. Rev. **D52** (1995) 4947.
17. S. Kretzer, Phys. Rev. **D62** (2000) 054001.
18. S. Kretzer, private communication.
19. B. Alper et al. (British-Scandinavian collaboration), Nucl. Phys. **B100** (1975) 237.
20. D. Antreasyan et al., Phys. Rev. **D19** (1979) 764.
21. M. Czech and A. Szczurek, nucl-th/0501026, Phys. Rev. **C72** (2005) 015202.
22. S. Albino, B.A. Kniehl and G. Kramer, Nucl.Phys. B725 (2005) 181-206, hep-ph/0502188.
23. S.S. Adler et al. (PHENIX collaboration), Phys. Rev. Lett. **91** (2003) 241803.
24. M. Czech and A. Szczurek, J. Phys. **G32** (2006) 1253, nucl-th/0510007.
25. M. Tichoruk, Doctoral Dissertation: Particles and jet production in high energy hadron collisions.